CHAPTER 2: BACKGROUND PRINCIPLES AND CONCEPTS

Introduction

The purpose of this handbook is to present EPA Region 6's GIS screening methodology and to serve as a manual for interested parties to replicate the tool for their own use. The tool is an environmental assessment tool developed to provide a more systematic approach to considering cumulative impacts in making environmentally sound decisions. It is designed to better understand the potential significance of single and cumulative effects and to facilitate communication of technical and regulatory data with industry, the public, and other stakeholders. The tool is not a training manual for impact assessment and users should be familiar with environmental impact assessment (EIA) in order to appropriately consider the vulnerabilities of and potential impacts on the affected environment. EPA and others (Costanza and Ruth 1998) are moving toward watershed or geographic approaches to assessment (TNRCC 1996, Caruso and Ward 1998). Cumulative impact assessments (Canter and Kamath 1995, Rees 1995, Smit and Spaling 1995, Cox and Piegorsch 1996, Piegorsch and Cox 1996, McCold and Saulsbury 1996, Burris and Canter 1997), use of GIS technology (Peccol et al 1996, Wang and Yin 1997, Dale et al. 1998, Zhang et al. 1998), watershed-based approaches (Wang and Yin 1997, Caruso and Ward 1998) and similar decision-making tools (Howard and Bunce 1996, Partidario 1996, Laskowski and Kutz 1998) have recently been the subject of journal articles and included in the agendas at environmental policy and scientific meetings.

The original impetus for the development of the tool began as a way for Region 6 NEPA staff to more objectively evaluate the information submitted by applicants and the potential cumulative impacts of swine feedlots (CAFOs) in Oklahoma and present this information to the decision-maker, EPA Regional Administrator, to determine where CAFO concentrations might have constituted a potential significant adverse impact (See Chapter 5) (Osowski, et al. 2001); however, the tool has been expanded and applied to a variety of projects since that time.

NEPA

The National Environmental Policy Act of 1969 (as amended) [42 USC §4321, 4331-4335, 4341-4347, 43724375] (NEPA) is one of the oldest and most comprehensive of our environmental laws. The language of the Act itself as well as the accompanying regulations (40 CFR §1500-1508) stress the importance of NEPA as good planning and as a process for decision-making. Within this process, analysts prepare Environmental Assessments (EA) or Environmental Impact Statements (EIS) that document the purpose and need of the project, existing environmental and socioeconomic conditions, environmental consequences, and alternatives. The discussion of alternatives to the proposed action is the heart of the NEPA process. The emphasis of NEPA since 1970 has been on direct, point sources of environmental impact and away from larger holistic assessments (O'Neill et al 1999). In developing alternatives, as well as investigating current conditions and environmental consequences, the NEPA document can be quite lengthy, technical, and may not be written in "plain language" understandable by the public-at-large.

McCold and Saulsbury (1996) found few court cases in which an inadequate assessment of cumulative impacts resulted in additional analysis being performed or an agency decision overturned. Overall, NEPA has not been effective in addressing or mitigating cumulative impacts that have continued to build up and subsequently become significant (McCold and Saulsbury 1996). With the advent of more powerful computers and GIS, cumulative impacts assessment is becoming easier and the analysis more objective than in times past.

Other literature has outlined shortcomings of the NEPA process, such as difficult-to-understand language (Sullivan et al. 1996), lack of post-assessment monitoring (Canter and Clark 1997), and uncertainty as to the requirements for assessing cumulative impacts (Burris and Canter 1997). The GISST helps to focus the Agency's assessment of potential impacts under NEPA and a way to monitor the effectiveness of project controls and mitigation holistically. As a screening tool, GISST helps to focus industry or permitee, Agencies, groups, and the public on a comparison among facilities, NEPA alternatives, or locations of vulnerable areas. Screening tools help establish better communication among stakeholders (Costanza and Ruth 1998).

Cumulative Impacts Assessment

The word "cumulative" has been defined in several different ways, depending on context. Words that are similar, even overlapping with cumulative, include "aggregate", "indirect", and "secondary" impacts. For example, within risk assessment, "aggregate" refers to the amount of one biologically-available chemical from multiple exposure paths (Moschandreas and Karuchit 2002), whereas "cumulative" refers to the accumulation of a toxin (or toxic effect) from multiple exposure routes and multiple contaminants (with a common toxicity) (Moschandreas and Karuchit 2002, Smits and Spaling 1995). Traditional risk assessment treats multiple exposures as independent events (US EPA 1999).

Within NEPA, “cumulative” refers to past and present actions. These actions could identify a significant cumulative impact on the environment; however, there is little agreement as to how past and present actions should be considered in the assessment process, and commonly, past conditions are included as a definition of the existing or baseline conditions within the assessment process (McCold and Saulsbury 1996). According to McCold and Saulsbury (1996) using a point in time when the environmental resource or condition was most abundant is a suitable baseline. Incorporating past and present conditions as part of the baseline, negates their contribution towards cumulative effects (McCold and Saulsbury 1996).

As NEPA practitioners have discovered, environmental assessments on single projects and the decisions arising from them do not mean that cumulative effects are assessed or determined to be insignificant. The traditional single media approach does not address complex environmental relationships (Mysz et al 2000). Single projects with minimal impacts may accumulate over time and space and then may equal a significant impact (Theobald et al 1997) or as Kahn (1966) termed it, the ‘tyranny of small decisions made singly.’ Cumulative impacts are not often fully addressed due to the complexity of these potential impacts, the lack of available data on their consequences, and the desire to limit the scope of environmental analysis. Unfortunately, potential cumulative impacts are rarely considered in decision-making processes because the methods available (e.g.,statistical, models, etc) are not practical in a regulatory arena (Abbruzzese and Leibowitz 1997). With the development and use of GIS, investigators can identify large scale impacts (O’Neill et al 1999) and impacts that were cumulative (Odum 1982). Mitigation opportunities are also affected by an inadequate cumulative impacts assessment (McCold and Saulsbury 1996). Abbruzzese and Leibowitz (1997) developed a framework for comparing landscape units by allowing consideration of cumulative impacts, especially in management decisions; the goal being a general evaluation of a region as a whole. They used four indices in their evaluation: 1) a function index that measured the amount of a specific ecological attribute, 2) the value of the ecological attribute or function related to social goals, 3) the functional loss of the function or attribute (i.e., cumulative impacts on the function/attribute), and 4) the ability to replace the specific ecological attribute and its function (i.e. replacement potential).

Watershed-Based Assessments

The holistic nature of watershed level assessments incorporates cumulative impacts in that multiple stressors (biological, socioeconomic, chemical, etc.) can be analyzed over a large spatial scale (Serveiss 2002), either one watershed or the aggregation of several. With the advent and subsequent increase in the use of spatial analysis tools such as GIS, regionally-scaled projects, planning and processes, such as those that use the ecoregion (Mysz et al 2000), watershed (Dickert and Tuttle 1985, Espejel et al 1999, Steiner et al 2000a, Steiner et al 2000b, Tinker et al 1998, Serveiss 2002), or other geographic boundary as a base unit, have become more commonplace. Reasons for using the watershed as the base unit for landscape-level assessments include functionality, biophysical processes, naturally-defined area vs politically-defined area, environmental impact assessment, holism, socioeconomic, and comparability/compatibility with other programs or areas (Steiner et al 2000a, Tinker et al 1998, Serveiss 2002). These tools have also inspired scientists concerned about landscape level patterns and change and their effect on terrestrial and aquatic communities (Jones et al 2001, Steiner et al 2000a). For example, Steiner et al (2000a, 2000b) stated that watersheds provide a framework in which to evaluate hydrological processes on wildlife habitat, land suitability for human development (residential, commercial, industrial). Using a watershed approach with risk assessment can lead to the increased use of monitoring data (Serveiss 2002). Watershed-level assessments are more holistic than assessments performed locally or those based on political boundaries because of their ability to relate potentially unrelated factors (Miller et al 1998) and for comparisons at other scales (e.g. several watersheds can be aggregated) (Montgomery et al 1995).

The watershed approach has also been used to analyze environmental problems that do not fit well into traditional programs or assessment methods (e.g. nonpoint source water pollution, regional studies) (Serveiss 2002, Boughton et al 1999) and those problems needing more holistic or comprehensive analysis (including decision making). Watershed-level assessments also lead to intergovernmental coordination on regulatory and management initiatives (Steiner et al 2000a, Serveiss 2002).

Decision Structures

Most tools use some sort of criteria or factors to evaluate the data layers used in the assessment (Steiner et al 2000b, Karydis 1996, Xiang 2001, Store and Kangas 2001). These ranks or scores help to simplify the analysis (Serveiss 2002), normalize disparate data sets onto one nominal scale (Clevenger et al 2002, Wickham et al 1999), and provide an easily understandable format to communicate the results to various audiences. These 'scores' are helpful in comparing NEPA alternatives or other aspects of projects since the ‘score’ represents the relative value of one alternative to another (Steiner et al 2000b, Wickham et al 1999, Abbruzzese and Leibowitz 1997). It also identifies ‘red flags’ (Theobald et al 2000) or issues that are inadequately addressed or are issues of concern within the environmental assessment process. These scoring systems may represent the difference between an ideal state of the environment and reality (Tran et al. 2002). However, this simple type of data integration has been criticized (Suter 1993).

When building an assessment tool, one of the things to consider is whether to weight individual “criteria” (Clevenger et al 2002, Abbruzzese and Leibowitz 1997) or to consider them all of equal weight. If weights are chosen, then the importance of the decision increases (Steiner et al 2000b).

The method that the GISST uses in terms of scoring and ranking could be considered as a multi criteria evaluation or MCE (Store and Kangas 2001, Clevenger et al 2002, Smits and Spaling 1995). MCE can include standardization of criterion scores, multiplication by weighting factor, and/or addition of all criterion scores (Store and Kangas 2001).

GIS

GIS is used in the development of assessment and screening tools not only because of its spatial data visualization abilities (i.e., maps of different data layers, coverages, landscape level, etc.), but also because of its modeling and analysis functions, including landscape metrics (e.g. FRAGSTATS), and other calculations (e.g., population density, hydrological functions). Thus, GIS has become a vital research and assessment tool (Ji and Leeberg 2002, Clevenger et al 2002, Dale et al 1994, Treweek and Veitch 1996, Iverson et al. 2001, O’Neill et al 1999), although Smits and Spaling (1995) predicted that GIS would not be broadly used for cumulative impacts assessment.

Since complicated modeling and analysis tools are less likely to be used in regulatory processes, Leibowitz et al (2000) suggest six properties of GIS assessment tools. These properties include 1) simplicity (not needing expert modeling abilities), 2) use of available data (rather than experimentation), 3) analytical (not needing numerical simulation), 4) approximate (need matches level of effort), 5) measurable change, and 6) expandable (use in more sophisticated models).

Relationship to SAB Report

In 2002, the EPA Science Advisory Board Ecological Processes and Effects Committee released a framework for assessing and reporting on ecological condition. The purpose of which was to guide practitioners on designing systems to assess and report ecological conditions. The framework also helps investigators to organize and decide what features to measure for a picture of ecological 'health.' Program goals and objectives are used to determine what essential ecological attributes will be used. There are six broad categories and several subcategories under each: landscape condition, biotic condition, chemical and physical characteristics, ecological processes, hydrology/geomorphology, and natural disturbance regimes. The set of six attributes can be used to determine ecological indicators, or characteristics of ecological systems, and specific measures and monitoring data used to determine the indicator or endpoint. It is a hierarchical structure where measures can be aggregated into indicators and indicators can be aggregated into attributes. The six attributes are independent of program goals and objectives, but serve as a stimulus for practitioners to decide what attributes and subcategories are essential to their project.

Like the GISST, not every attribute category or subcategory is appropriate in every situation; a user must select those criteria from the GISST or attributes from the SAB framework that provide the best measure and analysis of the project objective. Also, GISST is a much broader tool, in that it has socioeconomic, industry-specific, and other categories in addition to the ecological criteria. Table 1 shows the SAB ecological attribute categories, subcategories, suggested measure, and what GISST criterion corresponds. The SAB also suggests that the framework aids in designing the assessment and subsequent report in that it should "transparently record the decision tree and professional judgements used to develop it." Appendix A describes each GISST criteria, the ranking or decision tree, and definitions and assumptions associated with it. In addition, the cumulative nature of GISST follows the SAB framework of aggregating measures and indicators; therefore, both single 'media' and aggregate or cumulative effects (ecological, socioeconomic, etc.) can be considered.

The SAB also suggests that reference conditions be defined so that ecological indicators can be compared and later normalized for aggregation. This concept is imbedded within GISST as the 1 to 5 ranking structure serves to normalize disparate criteria values. Even though a 'reference condition' is not defined in GISST, it is a comparative risk tool in that NEPA alternatives, transportation alignments, etc. are compared against each other in a standard decision framework.

GISST adheres to the SAB framework in that it, in part, assesses ecological conditions, allowing users to analyze ecological condition, consequences, and suggest mitigation over watersheds or ecoregions. GISST also adheres to the framework by being 1) 'multimedia', useful to the traditional EPA programs (air, water, RCRA) as well as holistic programs such as NEPA; 2) interagency, a repository for coordinating other agency's data; and 3) understandable to non-scientists by using an intuitive 1 to 5 decision structure. In addition, GISST is 4) interdisciplinary, by incorporating socioeconomic, toxicity, and regulatory criteria (these are not a part of the SAB framework for assessing ecological condition).

Table 1. Relationship of the SAB framework ecological attributes to GISST criteria. (P) indicates the GISST criterion is provisional.

LANDSCAPE CONDITION

Category	**Subcategory**	**SAB example measure**	**GISST criterion**
Extent of habitat types		perimeter-area ratio	habitat fragmentation, patch area (P), TEAP Diversity
Landscape condition		number of habitat types	landscape texture (P), wildlife habitat TEAP Diversity, TEAP Composite
Landscape pattern		contagion	aggregation index (P), TEAP Diversity, TEAP Composite

BIOTIC CONDITION

Ecosystems & communities	community extent	extent of successional state	TEAP Diversity (Kuchler)
	community composition	presence of focal species	Protected habitat (P), TEAP Rarity

Category	Subcategory	SAB example measure	GISST criterion
	trophic structure	feeding guilds	TEAP Rarity (taxonomic richness)
	community dynamics	predation rate	NONE
	physical structure	tree canopy height	TEAP Sustainability (Kuchler)
Species & populations	population size	density	NONE
	genetic diversity	degree of heterozygosity	NONE
	population structure	age structure	NONE
	population dynamics	dispersal rates	NONE
	habitat suitability	focal species requirements	Combination of GIS layers
Organism condition	physiological status	hormone levels	NONE
	symptoms of disease	tumors, lesions	NONE
	signs of disease	tissue burden of contaminants	TRI weighted Air/Water releases

CHEMICAL AND PHYSICAL CHARACTERISTICS

Nutrient concentrations	Nitrogen	conc of N	Water Quality (STORET data)
	Phosphorus	conc of total P	Phosphorus budget
	other nutrients	conc of Ca, K, Si	NONE
Trace inorganic & organic chemicals	metals	Cu, Zn in sediment	NONE

Category	Subcategory	SAB example measure	GISST criterion
	trace elements	Se in water and soil	NONE
	organic compounds	methyl-Hg	NONE
Chemical properties	pH	pH in water & soil	NONE
	dissolved Oxygen	DO in streams	NONE
	salinity	conductivity	NONE
	organic matter	soil organic matter	NONE
	other	buffering capacity	NONE
Physical parameters	soil/sediment	temperature, texture	soil permeability, aquifer/geology ranking
	air/water	concentration of particulates	ozone nonattainment

ECOLOGICAL PROCESSES

Energy flow	primary production	tree growth	NONE
	net ecosystem production	CO_2 flux	NONE
	growth efficiency	carbon transfer	NONE
Material flow	organic C cycling	organic matter quality	NONE
	N & P cycling	N-fixation capacity	NONE
	other nutrient cycling	input/output budgets	NONE

HYDROLOGY & GEOMORPHOLOGY

Category	Subcategory	SAB example measure	GISST criterion
Surface & groundwater flows	pattern of surface flow	water level fluctuations	NONE
	hydrodynamics	water movement	NONE
	pattern of groundwater flows	depth to groundwater	Groundwater probability
	spatial salinity patterns	surface salinity gradients	NONE
	water storage	aquifer capacity	Aquifer/geology ranking
Dynamic structural characteristics	channel morphology complexity	length of natural shoreline	Water quantity
	dist. of connected floodplain	2yr or 10yr floods	100/500 Year Floodplain
	aquatic physical habitat	pool-riffle ratio	NONE
Sediment & material transport	sediment movement	sediment deposition	NONE
	particle size distribution	distribution of grain size	NONE

NATURAL DISTURBANCE REGIMES

	frequency	recurrence interval	NONE
	intensity		NONE
	extent	spatial extent	NONE
	duration	length of event	NONE